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THE EFFECT OF SOME PHYSIOLOGICAL FACTORS ON THE HYDROGEN-ION CONCENTRATION OF THE PLANT JUICE, AND ON THE GROWTH OF CORN SHOWING DIFFERENT DEGREES OF DISEASE INFECTION

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY

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Part I

INTRODUCTION

A number of workers have noticed a relation between the hydrogen-ion concentration of the plant juice and the reaction of certain plants to the attack of fungous diseases.

Harvey[8], for instance, working with beet and ricinus found the hydrogen-ion concentration less in the diseased areas than in the surrounding healthy tissue. Freeman Weiss and Harvey[30], on the other hand, working with potato wart discovered that the hydrogen-ion concentration was constantly greater in the warts than in the normal tissue. Wagner[28], after injecting pathogenic organisms into a variety of succulent plants, was able to show that there was an increase in the acidity of the juice. This increase was followed either by a return to normal or by a rapid decrease in acidity and death. Lately Hoffer[11] has reported that the hydrogen-ion concentration of the juice of the lower nodes of diseased corn plants is markedly less than that of disease free plants.

The acidity of the plant juice undoubtedly plays a very important physiological role in the development of the plant. It is hardly the province of this article, however, to go into a full discussion of this phase of the subject. It has been maintained that such functions as the permeability of the cell membranes, the rate of enzymatic reactions, the osmotic properties of the cell sap and the solvent powers of the plant juices are largely influenced by the reaction of the sap. And, while the findings reported in the previous paragraph are not consistent, they all seem to show that the entrance of pathogenic organisms into the plant tissue produces, either directly or indirectly, some significant change in the reaction of the juice. It is important to find out if these changes can be checked by

any external means and if certain pH values are associated with immunity to disease attack. With positive information on either of these points, we may be able to discover some way of preventing the inroads of the pathogenes, either by providing a suitable environment, or by some system of genetic selection.

The first thing to determine, however, is whether such changes do occur in the corn plant and, if so, if they can be influenced by external conditions. It was with this idea in mind that the following experiments were planned. Dent corn (Zea mays indentata), infected with both Fusarium moniliforme and Diplodia zeae, was chosen as the material to work on. It is estimated that the annual damage caused by these diseases in the United States is about five percent of the total crop. The economic importance of any method for their control can therefore be easily recognized.

MATERIALS

Seed The corn in this experiment was a strain of Reid's Yellow Dent, grown at Bloomington, Illinois. Unfortunately neither the diseased nor the disease free strain was entirely diseased or disease free. There were some disease free kernels in the diseased strain and some diseased seed in the disease free strain. There was, however, sufficient difference in the amount of disease infection to make the results obtained in this investigation reasonably conclusive.

Sand The quartz sand (flint silica) used was obtained from the United States Silica Company, Chicago. Its saturation coefficient when measured by the Hilgard shallow cup method[9] was twenty-three percent. As only comparative results were aimed at in this experiment, it was not thought necessary to wash the sand before use.

Chemicals In the preparation of the nutrient solutions, the methods outlined in the Bulletin of the National Research Council on "A Plan for Co-operative Research on Salt Requirements"[19] were closely followed. Baker's chemicals and Shive's optimum R_5C_2 solution were used in all the experiments. A departure was made in the case of iron. This element, as recommended in some later work of Jones and Shive[14], was added as $FeSO_4$ at the rate of .075 mgrm of iron per liter of sol. $CaCO_3$, screened down to particles between 1-1.5 mm in size, was added as commercial limestone. One gram per kilo was carefully mixed with the sand. Taking the weight of the surface 6 2/3" of soil as 2,000,000 pounds, this quantity corresponds to one ton per acre.

Pots Glass butter jars, holding about 1500 grms of dry sand each, were used as containers. They were surrounded by stiff paper to exclude the light.

Hydrogen-ion Apparatus Hydrogen-ion determinations were made by the hydrogen electrode. The apparatus used consisted essentially of (plate 1):

a Leeds Northrup Potentiometer, Leeds Northrup Galvonometer, type H, a n/10 calomel all made up according to Clark's[2] directions, a small cell modelled on the one devised by Haas[6], and a Palladium coated Platinum wire forming the hydrogen electrode. Compressed hydrogen, obtained from the Universal Oxygen Company, Sheyboygan, Wisconsin, and passed through alkaline pyrogallate and distilled water before reaching the electrode, was used as the source of hydrogen.

METHODS

Preparation of the pots The directions given by the National Research Council[19] were considerably departed from in setting up the pots. These were kept at sixty percent of saturation. This amount of moisture was found to give the best results in some preliminary trials. It is worth noting here that these tests, which were carried out in summer at a temperature of 32°-37°C, seem to show that the percentage of water in the disease free pots can be reduced to forty percent without markedly effecting the yield, but that a decrease to forty percent in the diseased pots brings about a distinct decrease in growth.

The sand was made up to the required moisture in a large mixing bowl and then shaken down uniformly into the different pots, while a glass tube, closed at lower end by a strainer made of a double thickness of cheese cloth, was held in position against the side of the pot until all the sand had been firmly shaken down.

Three kernels of corn per pot were then planted 1" below the surface of the soil and the pots sealed. The seal used consisted of fifteen percent vaseline and eighty-five percent parawax. At the laboratory temperature, the plants seemed to experience no difficulty in piercing this seal, which was poured on sufficiently warm to spread evenly.

Renewal of Solution The method of renewing the solution varied in the different experiments. The sand in each pot contained about 210cc of nutrient solution. This was usually changed twice a week. At the end of each three and one-half day period each pot was weighed and sufficient distilled water added through the cone to replace the moisture lost. All the easily removable water was then drawn off by an aspirator and 50cc of fresh solution was added. After this nearly all the free moisture was again drawn off and the

pots were made up to weight with fresh solution. This methcd required the addition of 100-120cc of solution at each aeration. In the earlier experiments no attempt was made to secure equal quantities of aeration when the solution was changed, but in experiments 11-12-13 this was secured by a device which will be described later.

Losses in transpiration were made up by the daily addition of distilled water.

Treatment of Pots These were placed on a rotating table (plate 2) which was kept in operation from 8 a.m. to 5 p.m. The temperature of the green house was maintained at 20-25°C and watered twice a day to keep the atmosphere moist.

Determinations Determinations were made as soon as possible after harvesting the plants. In no case was the period between harvest and the hydrogen-ion determination longer than two hours. During the interum, the plants were kept in a vasculum and the juice was tested immediately on extraction.

The tops were not washed, but the roots in each case were washed first in tap water then in distilled and finally dried on filter paper. The remains of the kernels were then cut off and the plants weighed.

The tops or roots of the three plants were ground up together in a porcelain mortar and the pulp collected on a small clean square of cheese cloth. This was squeezed out between two strips of stiff paper in a vice. The juice (each sample being the composite of three plants) was then tested without further treatment.

Readings were made in duplicate and the apparatus checked from time to time against a m/20KHPhthalate solution of known hydrogen-ion concentration.

A fresh electrode was used in each set of experiments. The capillary

tube at the end of the KCl bridge was very finely drawn out so as to limit the diffusion of the salt into the plant juice. After making the necessary temperature corrections, Schmidt and Hoagland's[23] tables were used for converting observed voltages to pH.

It may be well to point out here that, while the methods of extraction were of necessity rather rough, this disadvantage applied equally to the diseased and disease free corn and so did not interfere greatly with the comparative value of the results.

RESULTS AND DISCUSSION

Briefly, the object of the following experiments was to determine the difference in the hydrogen-ion concentration of the juice of diseased and disease free plants and the effect of several external factors on this acidity.

This could not be done, however, until the influence of several physical and physiological factors such as (a) Kind of seed, (b) Effect of sealing the pots, (c) Effect of variation in the amount of aeration, (d) The natural amount of variation in hydrogen-ion concentration to be expected in the juice of normal plants, had been first worked out. The first series of tests to be described were therefore planned to obtain data along these lines.

Germination Tests of the Seed Used

The seed used has already been described. Unfortunately it was not altogether either diseased or disease free as the case might be. Three tests were run using a total of one hundred kernels to determine the amount of disease infection.

The seed was germinated on Plaster of Paris blocks kept in a flat galvanized iron germinating pan with a close fitting lid. Both the pan and the blocks were boiled for thirty minutes before the seeds were placed on the blocks. As a result of this precaution, very little surface mold appeared on the blocks carrying disease free seed, though there was some growth of Rhizopus on the diseased blocks. The seedlings were grown for ten days at room temperature and then a disease count made by sectioning the kernels. All kernels showing discolored embryos were arbitrarily counted as diseased. The results are given in Table 1.

Germination Record of the Two Strains

Table 1.

Experiment	Number of Seeds		Number Germinating		Length of Shoot		Number of diseased plants in	
	D.F.	D.	D.F.	D.	D.F.	D.	D.F.	D.
1	25	25	25	24	12cm	15cm	7	18
2	50	50	50	49	11	15	11	39
3	25	25	25	25	11	13	6	18
Total	100	100	100	98	11.3	14.3	24	75

It is immediately apparent that the disease free strain contained many (twenty-four percent) apparently diseased kernels. The only significant difference that appears between the two is that the diseased strain contains about three times as many kernels showing Scutellum rot as the disease free. This proportion appears in all three trials.

Valleau[27] reported the same difficulty in securing entirely disease free seed, but he was able to demonstrate that the amount of infection shown in the original test was an indication of the final performance of the seed when grown to maturity. Some data in process of publication obtained by J. R. Holbert, in cooperation with the Illinois Experiment Station[12], show a similar close correlation between early vigor and subsequent yield. Scutellum discoloration on the germinator is not necessarily due to corn root and stalk pathogenes. It may be due to Rhizopus and other external infection. But, on the basis of Valleau's work and that of the Illinois Experiment Station just quoted, the two strains of corn used seem to show sufficient differences in vigor and in resistance to the development of disease to meet the requirements of this experiment. For the sake of convenience, the terms "disease free" and "diseased" have been adhered to in

the write up of this work. Although they do not accurately describe the status of the seed, they give a fair comparative description of the material worked with.

Effect of the Seal

Four pots were left unsealed in each of experiments 11-12-13. These unsealed pots were covered by inverted glass jars until the young shoots were through the soil, after which the jars were removed and the moisture content of the pots kept nearly constant by the addition of distilled water twice a day. The nutrient solution in these pots was changed in the ordinary way. Tables 2 and 3 give the results of these experiments.

Effect of Sealing the Pots on Yield

Table 2.

Experiment		Disease Free				Diseased			
		Tops		Roots		Tops		Roots	
		Seal	No Seal	Seal	No Seal	Seal	No seal	Seal	No Seal
11	No lime	2.95grm	6.20grm	2.47grm	4.69grm	3.05grm	3.70grm	2.86gm	2.47gm
12		4.62	5.15	3.38	3.70	2.69	2.00	1.78	.98
13		3.09	5.30	2.42	3.68	2.73	3.17	1.79	2.28
Average		3.55	5.55	2.76	4.09	2.82	2.96	2.14	1.91
11	Lime	5.60	3.92	4.20	3.47	2.30	3.46	1.78	3.70
12		6.21	5.55	3.58	3.93	2.36	5.15	1.36	3.70
13		4.56	5.49	3.30	3.62	3.54	2.00	2.75	1.70
Average		5.46	4.99	3.69	3.67	2.73	3.54	1.96	3.03

Effect of Sealing the Pots on Hydrogen-ion Concentration

Table 3.

Experiment		Disease Free				Diseased			
		Tops		Roots		Tops		Roots	
		Seal pH	No seal pH	Seal pH	No seal pH	Seal pH	No seal pH	Seal pH	No seal pH
11	No Lime	5.553	5.596	5.883	5.731	5.545	5.511	6.061	5.883
12		5.646	5.579	5.976	5.985	5.604	5.596	5.968	-
13		5.460	5.342	5.790	5.714	5.503	5.528	5.933	5.866
Average		5.553	5.506	5.883	5.843	5.531	5.545	5.987	5.874
11	Lime	5.503	5.562	5.790	5.731	5.579	5.511	5.900	5.883
12		5.562	5.545	5.832	5.900	5.587	5.511	5.942	5.850
13		5.426	5.461	5.798	5.765	5.410	5.528	5.900	5.866
Average		5.497	5.523	5.807	5.799	5.525	5.517	5.914	5.866

These results show that the seal had an unfavorable effect on the plants. In all the unlimed pots it reduced the total yield with the exception of the diseased pot in experiment 12, where the total yield was higher in the sealed pot. In this latter case, however, the plants in the unsealed pot happened to be so badly diseased that the effect of the disease pathogenes turned out to be greater than that of the seal.

In the limed pots the harmful effect of the seal on the disease free plants was apparently largely overcome by the addition of $CaCO_3$, but the damage was not decreased in the case of the diseased plants. As will be brought out later, the reason for this was due to the fact that sealing the

pots apparently greatly increased the effects of disease. So what was measured here was not really a decrease in the vigor of the plants, but an increase in the amount of disease damage.

The hydrogen-ion concentration of the tops was apparently not markedly effected by sealing the pots, but that of the roots was generally decreased. It was decreased in every case with diseased corn and in two out of three cases with the disease free corn. This can be explained, as later work will show, on the basis that the disease seemed to develop more readily on the sealed roots and they would consequently show less acidity.

Effect of Aeration It is only natural to expect that there would be a deficiency of air in the sealed pots. If this is the case, then the amount of air drawn through a pot at each aeration should have an important effect on the growth of the plants.

The apparatus illustrated by plate 2 was designed to test out this point. By means of this apparatus it is possible to draw a measured quantity of air (10 liters in this case) through the pots by watching the change of level of the water in the bottles. By having two bottles, as soon as the one is nearly empty, it is possible to reverse the suction and so do away with the necessity of refilling the empty bottle after the withdrawal of each ten liters of water. With the suction force available, it took four and one-half to five minutes to draw ten liters of air through each of the pots.

Twenty pots were set up in each of experiments 3 and 4. These twenties were divided into five groups which received different amounts of aeration, varying from ten liters once a day to none at all. In order to insure a more complete change of nutrient solution in those pots which were aerated at the longer intervals, the average amount of nutrient solution which was drawn off in Group 1 (daily aeration) was calculated. Then, during the aeration process and after about three liters of air had been drawn through the aspirator, this

quantity of solution was poured on each of the pots in Group 2. Three times this quantity was added in Group 3, and so on. In this way the same total quantity of solution was used in each pot. This, to a certain extent, does away with the possible effect of having unequal quantities of fresh solution in the different pots. For example, 100cc was changed at each daily aeration in Group 1 giving a total of 2800cc during the growing period; by changing 200cc at each of the every other day aerations in Group 2, the same total quantity of fresh solution was used.

Table 5 gives the results of these experiments.

Effect of Aeration

Table 5.

Experiment 3

Description of pot	Hydrogen-ion Concentration			Weights			Amount of Aeration	Number of D. Plants
	Soil Sol.	Tops	Roots	Tops	Roots	Total		
	pH	pH	pH	grms	grms	grms		
D.F.L.	5.602	5.427	5.816	5.45	3.98	9.43	Daily	1
D.F.	5.568	5.511	6.002	2.68	1.93	4.61		3
D.L.	5.838	5.444	5.917	4.11	3.20	7.31		2
D.	5.483	5.444	5.883	4.62	2.95	7.57		3
D.F.L.	5.872	5.376	5.797	5.22	4.00	9.22	Every 2 Days	2
D.F.	5.450	5.393	5.866	6.26	3.62	9.88		1
D.L.	5.872	5.444	5.934	2.93	1.95	4.88		3
D.	5.855	5.444	6.019	3.48	3.88	7.36		3
D.F.L.	6.092	5.461	5.883	5.65	4.38	10.03	Every 4 Days	3
D.F.	5.855	5.511	5.850	4.51	3.94	8.45		2
D.L.	6.126	5.393	5.866	2.38	2.22	4.60		3
D.	6.007	5.410	-	1.36	.70	2.06		2
D.F.L.	6.075	5.427	5.797	6.50	5.85	12.35	Every 8 Days	1
D.F.	6.026	5.376	5.833	3.76	2.45	6.21		1
D.L.	6.379	5.392	5.782	2.10	1.85	3.95		3
D.	6.143	5.444	5.866	2.70	2.05	4.75		3
D.F.L.		5.258	5.697	5.12	6.30	11.42	No Aeration	0
D.F.		5.325	5.765	4.05	4.60	8.65		2
D.L.		5.308	5.748	2.66	2.13	4.79		2
D.		5.327	-	1.12	.92	2.04		3

Table 5 continued.

Experiment 4

Description of pot	Hydrogen-ion Concentration			Weights			Amount of Aera.	No. of D Plants
	Soil Sol.	Tops	Roots	Tops	Roots	Total		
	pH	pH	pH	Grms	Grms	Grms		
D.F.L.	5.602	5.444	5.816	5,72	3.52	9.24	Daily	0
D.F.	5.365	5.325	5.833	4.78	3.97	8.75		2
D.L.	5.773	5.410	5.951	4.00	2.76	6.76		1
D.	5.500	5.444	5.816	4.80	3.61	8.41		2
D.F.L.	5.720	5.461	5.883	6.93	5.71	12.64	Every	1
D.F.	5.450	5.427	5.917	5.222	3.48	8.70	2	3
D.L.	5.652	5.528	6.052	3.40	2.08	5.48	Days	3
D.	5.382	5.511	6.002	2.98	2.20	5.18		3
D.F.L.	5.771	5.410	5.816	5.24	3.70	8.94	Every	1
D.F.	5.619	5.495	5.848	5.32	3.30	8.62	4	3
D.L.	5.871	5.427	6.103	3.35	2.80	6.15	Days	3
D.	5.500	5.393	5.866	3.04	1.81	3.85		3
D.F.L.	5.990	5.545	5.833	4.58	2.95	7.53	Every	3
D.F.	5.754	5.444	5.833	4.87	3.74	8.61	8	3
D.L.	5.990	5.393	6.255	2.60	1.76	4.36	Days	3
D.	5.754	5.528	-	1.57	.61	2.18		3
D.F.L.		5.393	5.799	4.02	3.57	7.59	No	3
D.F.		5.410	5.816	5.94	5.37	11.31	Aera-	1
D.L.		5.361	5.834	2.55	1.98	4.53	tion	2
D.		-	-	No	plants	-		3

D.F.L. Disease-Free Limed
D.F. Disease-Free (No lime)
D.L. Diseased Limed
D. Diseased (No lime)

From Table 5 it appears that once a pot is sealed, the amount of artificial aeration it receives makes no significant difference to the yield of plants. In both experiments the disease free plants receiving no aeration yielded as well as those aerated daily.

The amount of aeration does, however, make a difference to the development of the fungus. The progressively decreasing yields of diseased corn with the fewer aerations can be attributed to an increasing virulence of the disease. Though the plants in the frequently aerated pots were also diseased, they grew more vigorously while the pathogenes did not do so well (Plates 4 and 5).

This effect of the seal in increasing the amount of disease damage is brought out by Table 6. The data for this table were obtained by counting the number of diseased plants in, (a) the unsealed pots in experiments 11, 12, 13, (b) in all the sealed pots in experiments 11, 12, 13, (c) in all the pots in experiments 4 and 5. This gave the effect of sealed periods of no days, twenty-one days and twenty-eight days respectively.

Effect of Aeration on the Disease

Table 6.

Experiment	Days Under Seal	Total No. of plants	Number in each set	Percentage of Diseased Plants			
				Lime		No Lime	
				D. F.	D.	D.F.	D
11,12,13	0	36	9	22	33	10	55
11,12,13	21	72	18	28	33	33	83
4, 5	28	120	30	50	83	77	93

From Table 6 it appears that the longer the period the plants are under a seal (which is presumably equivalent to the absence of a free exchange of air), the greater is the amount of disease.

What is very interesting in this connection is that liming seems to reduce the number of plants showing pathogenic symptons, the percentage of apparently diseased plants being reduced from eighty-three to thirty-three in the sealed pots in experiments 11, 12 and 13. That $CaCO_3$ should decrease the development of disease is not altogether suprising. From work on pure cultures by Hopkins[13] and Webb[29], it appears that the most favorable pH on the acid side for the development of Fusarium sps and Gibberella saubinetii is under pH4.5 with a maximum inhibition at between a pH5 to pH6. Consequently the addition of lime should make the soil solution in the pots less favorable for the development of the disease organisms themselves.

These findings show the importance of giving careful consideration to the effects of liming and sealing in interpreting any of the results obtained by these experiments.

The Normal Variation in the Hydrogen-ion Concentration of the Plant Juice and the Correlation between this factor and Vigor

The hydrogen-ion of the plant juice is the product of a number of factors. It cannot be materially altered without disturbing the physiological activity of the plant. Therefore, one of the first things to determine in a study of this kind, is the amount of variation which can take place in normal plants without any noticeable disturbance in their external development. To do this satisfactorily calls for a much deeper study than the one made here. It is necessary, however, to get some idea of the amount of natural variation, or an effect attributed to liming or disease infection, may be nothing more than an expression of the normal difference, (assuming for the moment that

there is such a difference), in hydrogen-ion concentration between the juice of vigorous and less vigorous plants. It was hoped to throw some light on this problem by studying the green weights and hydrogen-ion concentration of the plants harvested on the unlimed pots, and so determine if there were any correlation between these weights and the acidity of the juice. Table 7 gives all these weights and the corresponding pH values.

Correlation between Vigor and Hydrogen-ion Concentration

Table 7.

No.	Tops				Roots			
	D. F.		D.		D. F.		D.	
	Weight	pH	Weight	pH	Weight	pH	Weight	pH
7	2.40	5.342	1.45	5.681	2.36	5.900	1.40	5.900
	3.98	5.478	2.56	5.376	4.76	-	1.36	5.748
8	4.35	5.275	4.13	5.308	2.72	5.444	3.63	5.561
	2.33	5.325	4.52	5.239	1.80	5.562	2.40	5.596
9	3.58	5.255	4.22	5.410	4.20	5.510	3.55	5.085
	5.55	5.410	5.08	5.376	5.46	5.850	3.87	5.731
	2.85	5.562	2.24	5.275	6.21	5.934	2.00	5.765
	2.38	5.444	4.13	5.511	2.47	5.799	3.12	5.951
10	3.66	5.511	2.60	3.393	3.33	5.850	1.73	5.765
	5.43	5.444	2.18	5.511	5.00	5.714	2.28	5.850
11	3.28	5.545	3.40	5.495	2.33	5.951	2.89	6.086
	2.63	5.562	2.71	5.596	2.72	5.816	2.83	6.036
12	3.73	5.714	2.28	5.647	3.59	6.052	1.56	5.968
	5.51	5.579	3.10	5.562	3.17	5.900	2.01	5.968
13	2.45	5.545	2.94	5.562	2.32	5.833	1.96	6.019
	3.74	5.376	2.52	5.444	2.52	5.748	1.63	5.850

From a general survey of this table it appears that there is some correlation between vigor and hydrogen-ion concentration, the more vigorous plants showing the greater acidity.

The differences are small but in six cases out of seven in disease free tops and in five cases out of seven in diseased tops, the more vigorous plants, judged on a green weight basis, show the greater hydrogen-ion concentration. To a certain extent this can be expected as the more active metabolism, which probably goes on in the faster growing plants, would naturally give rise to a larger amount of acid bye-products in the tissues.

The distinction is not so clear when it comes to the roots. Only in four cases out of six in the disease free plants, and in one case out of seven in the diseased plants, do the more vigorous roots show the greater acidity. Here, however, the complicating factor of disease comes in. The diseased roots were all so badly diseased that, as will be pointed out later, the effect of disease probably overbalanced that of vigor.

A Possible Difference in the Nutrient Requirements of the Plants

As the experiments progressed it became evident that lime was having a detrimental effect on the diseased corn.

Numerous workers, among whom are McCall and Haag[18], Jones and Shive[15], Duggar[15], Salter and McIlvaine[22], and Hoagland[10], have repeatedly shown that the hydrogen-ion concentration of a solution can be changed by the plants growing in it. No conclusive evidence has yet been produced, however, to show what is the optimum pH value in any solution for the growth of plants. It seems probable that, for the three salt solution used, it lies between pH4.8 - 5.2, though considerable departures from these figures often have no effect. It seemed, therefore, possible that one reason why the diseased plants

were not doing well was that lime was making the nutrient solution too alkaline. Beneke[1], growing corn in Von der Cronen's solution, was able to show that an acid solution often favors root growth even though it does not give such good results with the tops. To determine if this were the case here, the hydrogen-ion concentration of the nutrient solution in the pots was determined at the end of the growing period in experiments 4, 5, 11, 12 and 13. The results are given in Table 8.

The Effect of Plants on the Hydrogen-ion Concentration of Soil Solution

Table 8.

No.	Lime				No Lime			
		D. F.		D.		D. F.		D.
	Sealed Pots							
4	2	pH 6.092	3	pH 6.126	2	pH 5.855	2	pH 6.007
5	0	5.771	3	5.871	3	5.619	3	5.500
11	2 0	6.092 5.940	1 0	6.210 6.092	0 0	5.754 5.534	2 3	5.771 5.788
12	0 1	5.647 5.732	0 2	6.052 5.664	2 1	5.596 5.528	3 2	6.019 5.664
13	1 1	5.664 5.702	1 2	5.731 5.664	2 1	5.596 5.545	2 3	5.495 5.528
Average		pH5.836 ± .039		pH 5.926 ± .049		pH 5.628 ± .026		pH 5.722 ± .047
			Unsealed Pots					
11	0	6.278	1	6.312	0	5.585	1	5.855
12	1	5.883	0	5.968	1	5.748	2	5.900
13	1	5.681	1	5.681	0	5.478	2	5.579
Average		5.947		5.987		5.604		5.778

Columns 2, 4, 6 and 8 give the number of D.iseased plants in each pot. The total number of plants per pot was three.

The average difference in pH of .090 between the limed disease free and diseased pots seems too small to account, on the score of alkalinity, for the wide difference in the yields of the two sets. The interesting thing about Table 8 is, however, that the pots with diseased plants in them appear to end up generally a little less acid than those growing disease free plants. This difference is also brought out by comparing the disease free pots in which some of the plants were diseased. Generally the pots harbouring the larger number of diseased plants are less acid than those containing fewer diseased plants.

The experimental error is too large to make these differences significant, but they seem to indicate a larger absorption of the anion, or acid radicle~~s~~, in the nutrient solution by the diseased corn. The possibility that this difference in hydrogen-ion concentration is due to a larger excretion of CO_2 by the disease free roots can be dismissed for two reasons: in the first place, any accumulation of CO_2 in the pots would have diminished the root growth in those pots in experiments 4 and 5 which were aerated only at long intervals - this did not happen - Clements[30] in a recent symposium on aeration summarizes the work of a number of investigators which supports this contention; secondly, the sweep of air through the pots in the taking of the samples would probably have equalized the CO_2 saturation in all the solutions drawn off.

It is not possible to say which of the anions has been absorbed, but as the acidity of the solution is due to the H_2PO_4 ion of the KH_2PO_4, it seems very likely that this ion has been absorbed for the purpose of supplying either extra P or an acid radicle to the diseased plants.

In interpreting these results, the effect of the sand itself on the pH of the nutrient solution should be taken into account. Both Shive[24] and

Hoagland[10] have reported that the hydrogen-ion concentration of a nutrient solution is not markedly affected by the addition of quartz sand. Both these workers, however, washed their sand carefully (Hoagland taking the further precaution of treating the sand with HCL) and thoroly flooded the sand at each change of nutrient solution. The sand in this experiment was not washed or so extensively irrigated and an effect of some alkaline reacting materials was noticed. But as this initial effect would be practically overcome by the end of the growth period and would effect both strains in the same way, it does not interfere with the comparative value of the hydrogen-ion concentration of the final solutions drawn off.

Comparison of the Hydrogen-ion Concentration of Diseased and Disease Free Corn

Table 9, which gives the hydrogen-ion concentration of all the plants grown in the unlimed pots in experiments 7 to 13, brings out the differences between the two strains.

Hydrogen-ion Concentration of Diseased and Disease Free Corn

Table 9

Experiment		Tops			Roots			
		D. F.	D.		D. F.		D.	
7		pH 5.342		pH 5.681		pH5.900		pH 5.900
		5.478		5.376		-		5.748
8		5.275		5.308		5.444		5.501
		5.325		5.239		5.562		5.596
9	1	5.255	2	5.410	1	5.510	2	5.985
	1	5.410	1	5.376	1	5.850	1	5.731
	2	5.562	2	5.275	2	5.934	2	5.765
	3	5.444	3	5.511	3	5.799	3	5.951
10	0	5.511	2	5.393	0	5.850	2	5.765
	1	5.444	3	5.511	1	5.714	3	5.850
11	0	5.545	2	5.495	0	5.951	2	6.086
	0	5.562	3	5.596	0	5.816	3	6.036
12	2	5.714	3	5.647	2	6.052	3	5.968
	1	5.579	2	5.562	1	5.900	2	5.968
13	2	5.545	2	5.562	2	5.833	2	6.019
	1	5.376	3	5.444	1	5.748	3	5.850
	14	Av 5.460	28	Av 5.462	14	Av 5.791	28	Av. 5.861
		± .021		± .021		± .029		± .023

Columns 2, 4, 6 and 8 give the number of diseased plants in each pot. The total number of plants per pot was 3.

This table shows that there is no specific difference in hydrogen-ion concentration between the two strains. The acidity of the two sets of tops (pH 5.460 and 5.462) is practically the same and the difference in the roots is not significant.

When, however, disease free or diseased plants in the same experiment (such as those in the two disease free pots in experiment 12) are compared inter se, the pots with the smaller number of diseased plants will generally be found to contain the plants with the more acid juice. This holds true, where data are available, in three cases out of four in disease free tops, four cases out of five in diseased tops, three out of four with disease free roots and one out of five cases with diseased roots. It is again difficult to see why the diseased roots do not follow the general lead of the tops. However, the diseased roots were nearly all so badly diseased that some plants among them classified as apparently disease free may have been diseased. In any case, it is significant that this group has the lowest average hydrogen-ion concentration.

Whether this lowering of acidity is directly due to the activities of the disease organisms, or to a lowering of the vigor of the plants, or to both, is not clear. It was pointed out in the introduction to this article that an alteration in the acidity of the plant juice, as the result of the development of pathological conditions, has been reported by several writers. Among these workers are Hoffer and Carr[11]; R. B. Harvey[8]; Freeman Weiss and Harvey[30]; and Wagner[28]. The work of the last named investigator is of particular interest in this connection. After he had injected the disease cultures into the tissues of various succulent plants, he managed to follow the actual development of the disease. He found at first a decided increase in the hydrogen-ion concentration which was followed by a return to the

normal of the plant if it were going to recover, but by a decrease in acidity if it were going to succumb. The diseased plants reported in Table 9 seem to show a lowering of hydrogen-ion concentration very similar to the premortal drop in Wagner's infected plants.

Influence of Liming on the Yield of Corn

Liming is popularly supposed to be beneficial to diseased corn, and one object of these experiments was to determine whether this improvement is due to a specific effect of the lime on the diseased corn, or to the general improved soil conditions brought about by its application.

Any effect obtained by the addition of $CaCO_3$ in these experiments would probably be due either to its specific properties or to its physiological effect on the plant itself, for it is hard to see how liming can have any significant effect on the physical or biological conditions in the kind of sand used for experiments.

In each set of experiments half the pots were always limed and half left unlimed as checks. The yields of the two sets are given in Table 10.

Effect of Liming on the Yield of Corn

Table 10.

	Disease Free						Diseased					
	Lime			No Lime			Lime			No Lime		
	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
	Gms	Gms	Gms	Gms	Gms	Gms	Gms	Gms	Gms	Gms	Gms	Gms
6	4.60	5.00	9.60	3.40	2.30	5.70	2.68	3.75	6.43	4.35	3.65	8,00
	4.52	3.95	8.47	4.05	4.10	8.15	3.70	4.05	7.75	3.85	2.85	6.70
7	4.95	3.85	8.80	2.40	2.36	4.76	2.62	2.62	5.24	1.45	1.40	2.85
	4.16	3.58	7.74	3.98	4.76	8.74	.70	1.58	2.28	2.56	1.36	3.92
8	4.76	4.05	8.81	4.35	2.72	7.07	3.50	3.70	7.20	4.13	3.63	7.76
	4.50	3.74	8.24	2.33	1.80	4.13	-	-	-	4.52	2.40	6.92
9	4.06	3.70	7.76	3.58	4.70	7.78	2.71	2.60	5.31	4.22	3.55	7.77
	2.45	2.08	4.53	5.55	5.46	11.01	3.22	3.55	6.77	5.08	3.87	8.95
	4.18	4.75	8.93	2.85	3.21	6.06	1.40	1.86	3.26	2.24	2.00	4.24
	4.10	6.00	10.10	2.38	2.47	4.85	2.00	2.20	4.20	4.13	3.12	7.25
10	5.35	4.52	9.87	3.66	3.33	6.99	2.58	2.26	4.84	2.60	1.73	4.33
	3.60	3.25	6.85	5.93	4.50	9.43	2.08	1.43	3.51	2.18	2.28	4.46
11	5.65	4.18	9.83	3.28	2.23	5.51	1.12	1.00	2.12	3.40	2.89	6.29
	5.55	4.22	9.77	2.63	2.72	5.35	3.48	2.57	6.05	2.71	2.83	5.54
12	6.67	3.80	10.47	3.73	3.59	7.32	2.32	1.22	3.54	2.28	1.56	3.84
	5.76	3.37	9.13	5.51	3.17	8.68	2.38	1.50	3.88	3.10	2.01	5.11
13	4.51	3.02	7.53	2.45	2.32	4.77	3.22	2.65	5.87	2.94	1.96	4.90
	4.61	3.58	8.19	3.74	2.52	6.26	3.87	2.86	6.73	2.52	1.63	4.15
	4.67	3.92	8.59	3.63	3.21	6.84	2.56	2.44	5.00	3.24	2.48	5.72
Av.	± .12	± .13	± .22	± .16	±.15	±.29	±.14	±.14	± .27	±.15	±.12	±.27

These results are very interesting as the addition of lime, while it significantly increased the average yield of tops roots and green weight in the case of disease free corn, was not favorable to diseased corn. There was a marked decrease in the green weight of tops in the diseased corn and certainly no improvement in regard to roots or total green weight.

As liming reduced the number of diseased plants in these experiments, it seems strange that it should have reacted unfavorably on the yield of these same plants.

It would seem that either $CaCO_3$ has decreased the availability of the acid phosphate radicle which, as brought out by Table 8, may be more urgently required by diseased than by disease free plants - in the presence of the CO_2 of the roots, the $CaCO_3$ may have done this by combining with some of the KH_2PO_4 to form less soluble $CaHPO_4$ - or, as True[25] pointed out in an opposite connection, it may have affected the absorptive properties of the cell walls in some way so as to render certain of the ions in the nutrient solution physiologically less available. The former seems to be the more reasonable explanation.

It hardly needs pointing out here that temperature relations are very important in studying the effects of calcium. These results were obtained at a temperature of 20° - 25°c and may not hold at other temperatures. Portheim[21], growing beans in nutrient solutions, showed that the demand for Ca rose as the temperature was increased, and in the preliminary moisture tests run to determine the optimum soil moisture content for these experiments, Ca gave favorable effects on diseased plants at a temperature of 32° - 37°c. When there is a variation in time of planting or season, some of the seemingly inconsistent results obtained in the field may be due to a similar change in the temperature relations.

Influence of Liming on the Hydrogen-ion Concentration of the Juice

From the work of Haas[6], Clevenger[4], Truog and Meacham[26], it was expected that liming would reduce the acidity of the plant juice. In these experiments it did not significantly do so. This is brought out by Table 11, which gives the hydrogen-ion concentration of all the plants grown in experiments 7-13.

Influence of Liming on the Hydrogen-ion
C Concentration of the Juice

Table 11.

	Disease Free				Diseased			
	Tops		Roots		Tops		Roots	
	Lime pH	No Lime pH	Lime pH	No Lime pH	Lime pH	No Lime pH	Lime pH	No Lime pH
7	5.495 5.427	5.342 5.478	5.816 5.731	5.900 -	5.647 -	5.681 5.376	5.900 -	5.900 5.748
8	5.393 5.359	5.275 5.325	5.816 5.934	5.444 5.562	5.410 -	5.308 5.239	5.681 -	5.561 5.596
9	5.393 5.427 5.495 5.410	5.255 5.410 5.562 5.444	5.816 5.866 5.900 6.052	5.510 5.850 5.934 5.799	5.428 5.511 5.562 5.359	5.410 5.376 5.275 5.511	6.137 6.188 6.102 6.103	5.985 5.731 5.765 5.951
10	5.562 5.613	5.511 5.444	5.799 5.917	5.850 5.714	5.461 5.359	5.393 5.511	5.799 5.816	5.765 5.850
11	5.528 5.478	5.545 5.562	5.782 5.799	5.951 5.816	- 5.579	5.495 5.596	- 5.900	6.086 6.036
12	5.478 5.647	5.714 5.579	5.782 5,883	6.052 5.900	5.596 5.579	5.647 5.562	5.951 5.934	5.968 5.968
13	5.511 5.342	5.545 5.376	5.866 5.731	5.833 5.748	5.410 5.410	5.562 5.444	5.816 5.985	6.019 5.850
Av.	5.472 ± .014	5.460 ± .020	5.849 ± .013	5.790 ± .029	5.485 ± .018	5.462 ± .022	5.947 ± .024	5.861 ± .025

Though in every case liming seems to slightly reduce the average

hydrogen-ion concentration, the differences are not large enough to be significant. What may have happened is brought out by Table 12, which summarizes the simultaneous effect of liming on acidity and yield (Tables 10 and 11). A plus value in the pH column of Table 12 naturally indicates a decrease in acidity.

Summary of the Influence of Liming on Hydrogen-ion Concentration and Yield

Table 12

	Disease Free				Diseased			
	Tops		Roots		Tops		Roots	
	Average Yield	Average pH	Average Yield	Average pH	Average Yield	Average pH	Average Yield	Average pH
7	+1.36 grs	+.051	+.15 gms	-.126	-.34 gms	+.118	+ .72 gm	+.076
8	+1.29	+.076	+1.63	+.372	-.82	+.136	+ .68	+.102
9	+.11 gms	+.013	+.30	+.135	-1.58	+.072	- .58	+.274
10	-.07	+.110	-.03	+.076	-.06	-.042	- .16	±.0
11	+2.64	-.050	+1.72	-.093	-.75	+.033	- 1.07	-.161
12	+1.59	-.084	+.20	-.143	-.34	-.017	- .42	-.025
13	+1.46	-.034	+.88	+.008	+.81	-.093	+.96	-.34

From Table 12 it appears that the hydrogen-ion concentration of the tops may be actually increased in case of plants markedly benefitted by the application of lime. This increase is shown by the disease free tops in experiments 11, 12 and 13, where liming produced its maximum favorable effect,

and by the diseased tops in experiments 10, 12 and 13 (though not in 7) where the effect of liming, though not favorable, was least detrimental.

The effect of liming on the hydrogen-ion concentration of the roots seems to follow no sort of recognizable rule. The acidity actually increased without any particular relation to yield in three cases out of seven in both the disease free and diseased corn.

All through these experiments the reactions of the roots are far harder to explain than those of the tops. The reason for this may be in some internal regulatory power of the roots. Probably they can regulate their hydrogen-ion concentration, despite the lime, so as to function physiologically as well as possible for the conditions under which they have to grow. This power of the roots is brought out by Table 5 where, despite wide variations in the hydrogen-ion concentration of the nutrient solution in the pots, the acidity of the roots shows very little change. In experiment 3, the roots in the disease free limed pots, with a variation in pH of the soil solution of pH 5.602 to pH 6.092, show a variation of only pH .085. In experiment 4, with approximately the same soil range, the same plants show a root variation of only pH .051.

This power of the roots to largely regulate their own hydrogen-ion concentration seems to be one explanation why hypotheses, which fit the reactions of the tops so well, are not nearly so satisfactory for the roots.

In conclusion it may be well to point out that a great deal of the variation obtained in experiments on corn root and stalk diseases is probably due to differences in the seasonal vigor of the plants. Any treatment or favorable environmental condition, which increases the vigor of the plant, probably increases its resistance to disease. If the season or soil treatment is rendered more favorable to a vigorous growth of the corn plant, strains which one season show a large percentage of disease, in the next may show

only a slight amount of infection.

A very large proportion of the seed corn in the corn belt is infected with organisms capable of producing a diseased condition of the root or stem, but how much of this disease will actually develop depends on both the inherent vigor of the plants and on the environmental conditions.

The work reported in this paper tends to show that whenever the conditions are rendered unfavorable to the development of the plant either by sealing the pots, reducing aeration, applying $CaCO_3$ or reducing the percentage of soil moisture, there is an immediate increase in the amount of disease damage in the diseased corn. This increase is due largely to the fact that the diseased corn, being less vigorous than the disease free, is not so able to withstand the unfavorable environment and is thus more readily susceptible to the attacks of pathogenes. Under happier circumstances the diseased plants could probably hold their own. The environmental conditions may play nearly as important a role in overcoming disease infection as any inherent resistance in the seed itself.

SUMMARY

The value of these results is somewhat minimized by the fact that the seed used was not entirely disease free or diseased. There seems to be, however, sufficient difference in the severity of disease infection in the two strains to allow the following conclusions to be drawn:

For plants grown under the experimental conditions described it appears that:

(1) Until the diseased condition is well developed, there is no significant difference between the hydrogen-ion concentration of corn showing a large percentage of infection on the germinator and that showing a smaller percentage.

(2) The effect of the disease is to reduce the hydrogen-ion concentration of the plant juice.

(3) There is a correlation between the vigor of the plant and the hydrogen-ion concentration of the juice, the more vigorous plants usually being the more acid.

(4) Lime decreases the yield of badly diseased corn but increases that of corn showing a slight amount of infection. This may be due to a larger demand by the diseased corn for the phosphate radicle in the nutrient solution.

(5) Liming seems to have no specific effect on the hydrogen-ion concentration of the plant juice. Where it increases the vigor of the plants it increases the hydrogen-ion concentration and vice versa.

Part II

INTRODUCTION

This field trial was planned to determine whether it is possible to detect any difference in the hydrogen-ion concentration of the plant juice of apparently diseased and disease free corn grown under field conditions. It was also planned to secure at the same time some data on the normal variation in hydrogen-ion concentration due to such factors as Age, Weather and Liming. The methods involved are of necessity rough, but they indicate the changes that may be expected in ordinary farm practice.

The literature covering such a broad investigation is naturally very extensive. No attempt is made to give it full treatment here. There are good descriptions of the disease and its development in the publications of the United States Department of Agriculture, Illinois, Purdue, Delaware, Kentucky and other experiment stations[31], where corn root rot has been carefully studied under field conditions.

MATERIALS

Soil A fairly uniform piece of land with a slight southern slope and about one-half acre in extent was chosen for this experiment. The soil of the plot is a brown silt loam, typical of central Illinois. It had grown alfalfa from 1913 to 1918, corn in 1919, oats in 1920. In 1919 and 1920, two tons of chicken manure were applied to it each year.

Seed The seed corn used was obtained from J. R. Holbert, Bloomington, Illinois, and had been carefully selected to give disease free, diseased composite (seed infected with either Fusarium, or Diplodia, or both), Diplodia infected, Fusarium infected and nearly disease free seed (no Diplodia or Fusarium infection).

As the experiment progressed no difference in hydrogen-ion concentration could be noticed between the different strains. Therefore, in order to narrow down the problem, only plants in the disease free and diseased composite rows were used in securing data for the final results.

Twenty rows of corn were planted, four of each kind. Each row consisted of forty hills, excluding guard rows, with three kernels to the hill. The rows ran north and south.

Lime was applied east and west over the southern half of the plot at the rate of twelve tons per acre. In each row twenty hills were therefore on limed and twenty on unlimed soil. Two guard rows separated the limed from the unlimed corn.

Course of Growth The plot was planted with a hand planter on May 18, 1921. Heavy rains on May 26 washed out one corner of the limed part of the field and it was necessary to replant this May 31. This corn never quite caught up to the earlier planting and it was not possible to use any of it until near the end of the experiment. The plot was cultivated on June 7 and 8.

Up to the middle of July very little difference was noticeable between the diseased and disease free corn, or between the limed and unlimed rows. The whole crop made a vigorous growth and germination, tassel and smut counts did not show any marked difference either between the different strains or from the lime treatment.

On July 27, ten leaning stalks were noticed in the Diplodia and Diseased Composite rows on the unlimed soil. On July 31, there were thirty leaning stalks on the unlimed and twelve on the limed soil distributed without much difference between the various rows. During August the limed plot gradually improved in comparison with the unlimed and by September showed decidedly the more vigorous stand. A count of leaning stalks made on September 1, disclosed forty-five leaning stalks on the unlimed and eighteen on the limed soil.

The corn matured about September 21. No general harvest was made, however, as a large number of plants had been pulled up indiscriminately for testing purposes, which made it impossible to get a truly comparative count on the remaining rows.

METHODS

Plants were collected at irregular intervals throughout the growing season.

In this experiment there was no noticeable difference in the appearance of the diseased and disease free plants in their earlier stages of growth. The plants pulled in the diseased and disease free rows all seemed externally healthy. Therefore, in order to secure uniformity, the practice of only pulling plants which seemed externally disease free from both the diseased and disease free rows was adhered to until the end of the experiment. When obviously diseased material became available in August and September, it was harvested and examined quite separately. In this way, assuming the corn was diseased and disease free as described, it should be possible to show whether any change in hydrogen-ion concentration preceded or followed the development of the disease.

Plants were dug up by the roots and conveyed at once to the laboratory. In each case the plants selected were externally sound and typical of the general state of development of the crop at the time. Each sample consisted of three plants from separate hills. Samples were always taken between 8 and 9 a.m.

The laboratory methods and procedure were essentially similar to those described in the forepart of this paper.

A section 2" long with the lower node in center was cut from each plant and the brace roots trimmed off. The three nodes were sliced up and then passed through a tinned meat grinder. As there was very little adherent soil on these nodes, they were not washed before grinding.

The roots, on the other hand, were first washed in tap water until free from soil. Then twice rinsed in distilled water and dried with a clean towel. An aliquot sample of the roots of each of the three plants was then taken and the mixture passed through the grinder.

All tests were run in duplicate and the apparatus repeatedly checked against a KH Pthalate solution of known hydrogen-ion concentration.

RESULTS AND DISCUSSION

Under controlled conditions the acidity of the plant juice is held to vary with the time of day, atmospheric conditions and age of the plant. The effect of these factors on the two strains of corn had, therefore, to be first determined before any satisfactory comparison could be made of their hydrogen-ion concentrations.

To determine this effect approximately, a record of the temperature, atmospheric humidity, sky conditions and stage of maturity of the plants was kept throughout the experiments. At the end of the experiment this data was plotted to find out whether there was any traceable correlation between these environmental factors and the hydrogen-ion concentration of the plants.

The weather records were obtained from the University of Illinois Weather Station. The stage of maturity was that shown by those plants actually pulled for testing.

The data obtained are summarized inthe following tables. Unfortunately they apply to only one season and so cannot be taken as giving more than an indication of what may go on in the plant.

The Influence of the Time of Day on the Hydrogen-ion Concentration of the Plant Juice

As all samples were collected between 8 and 9 a.m., it was not thought necessary, for the purposes of this experiment, to specifically check the diurnal variation in hydrogen-ion concentration.

The Influence of Atmospheric Conditions on the Hydrogen-ion concentration of the Plant Juice

A record of the atmospheric conditions at the time the plants were collected was obtained each day from the University Weather Station. These data were summarized at the end of the season so as to find out if there were any correlation between the environmental conditions and the acidity of the plant juice. Unfortunately no determinations were made of soil moisture, which may have had a potent effect on the results.

The plants used in compiling the data on atmospheric conditions were all grown on the unlimed soil. The results are summarized in Table 1.

Effect of the Atmospheric Conditions on the Hydrogen-ion Concentration of the plant juice

Table 1.

Date	Disease Free	Diseased	Sky	Rel. Humidity	Temp.	Atmospheric conditions for previous 24hrs
July 7	pH5.740	pH 5.807	cloudy	62%	81°F	cloudy
18	5.765	5.647	clear	57	75	clear
28	5.444	5.410	cloudy	42	90	cloudy
Aug. 1	5.511	5.545	clear	55	70	clear
8	5.782	5 .441	clear	63	66	cloudy
9	5.731	5.748	clear	74	63	clear
16	5.800	5.716	cloudy	79	63	cloudy
Sept. 7	5.427	5.461	clear	69	66	clear
13	5.508	5.579	cloudy	72	69	cloudy
20	5.511	5.596	clear	92	72	cloudy
26	5.562	5.748	clear	42	70	cloudy

According to the standard texts of Pfeffer and Jost, illumination, high temperature, and any influences which induce "copious transpiration", decrease the acidity of the sap. Similarly Long, in some more recent work,

was able to show that the acidity of the outer regions of certain cacti was markedly decreased by the joint influence of light and temperature.

From Table 1, it would seem, however, that the acidity of the corn under study was controlled by physiological factors, which were stronger than the environment. On July 28, for instance, when a relative decrease of acidity was expected, the very reverse condition took place. Similarly on August 16, when with a relatively high humidity and low temperature, an acid sap was looked for, the lowest hydrogen-ion concentration of the season was recorded.

Either the variation in early morning and over night atmospheric conditions was not severe enough to bring about a noticeable change in acidity, or else the methods of sampling were too rough to detect it. What is significant for our purpose is, however, that the diseased and disease free strains both seem to vary in the same direction.

Effect of Age on Hydrogen-ion Concentration

This was studied on apparently uninfected diseased and disease free plants from the unlimed soil. The results are given in Table 2 and are illustrated by Figure 1.

The Effect of Age on the Hydrogen-ion Concentration Of the Plant Juice

Table 2.

Date	Age in Days	Disease Free	Diseased	Stage of Development
July 7	50	pH 5.740	pH 5.807	Vegetative
18	61	5.765	5.647	Tassel
28	71	5.444	5.410	Milk
Aug. 1	74	5.511	5.545	
9	82	5.731	5.748	
16	89	5.800	5.716	Soft dough
Sept. 7	111	5.427	5.461	Dough
13	117	5.508	5.579	Glazing
20	124	5.511	5.596	
26	130	5.562	5.748	Ripe

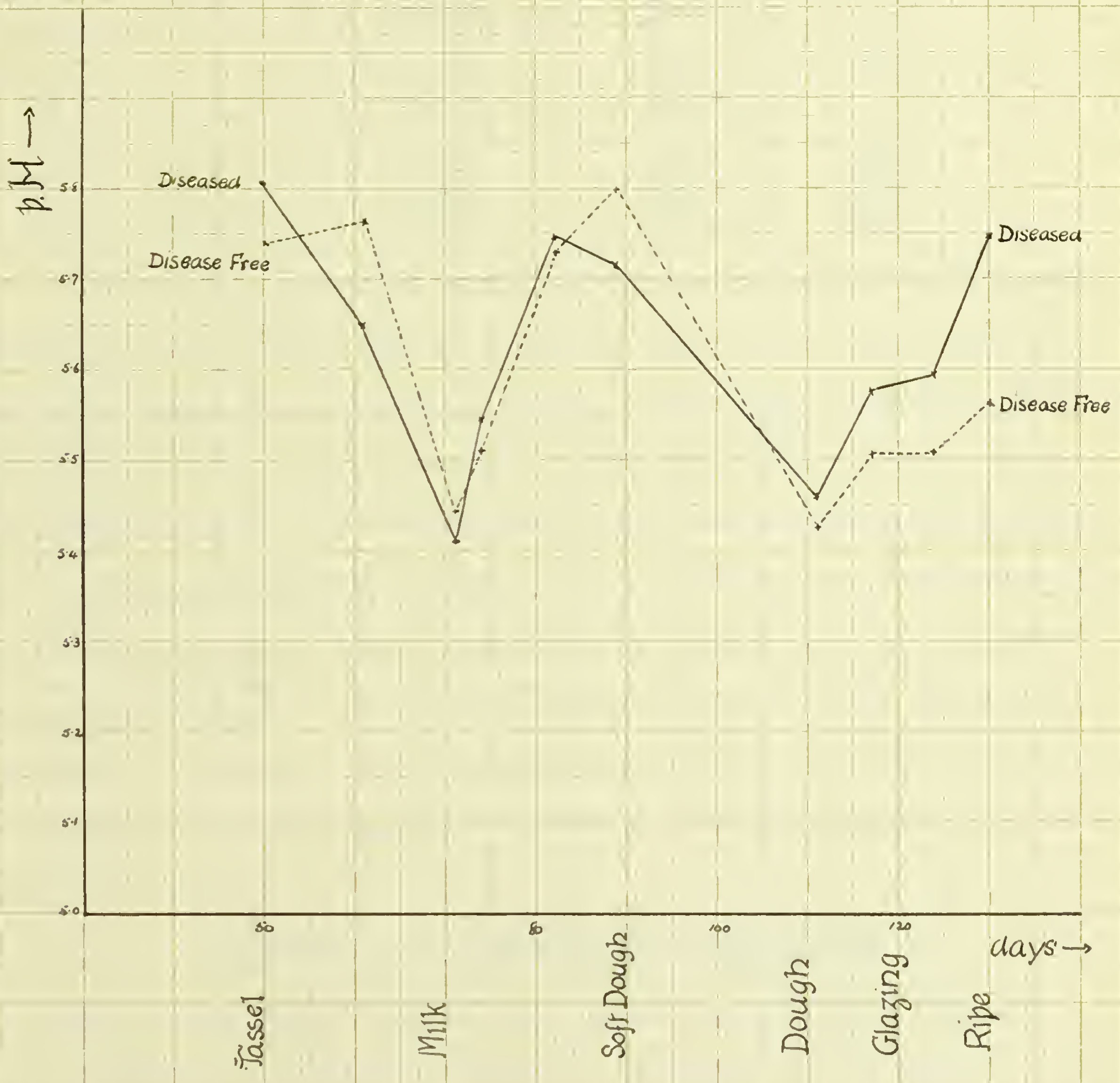
The greatest hydrogen-ion concentration was reached about the milk stage with a subsequent gradual disappearance of acidity as maturity was approached. The variation ran almost parallel in the two strains and the assumed presence of disease does not seem to have interferred at all with the normal physiological changes. No explanation occurs to us for the extremely low hydrogen-ion concentration in August. From the temperature and humidity records the very opposite was expected.

Since environment and age seem to effect the two strains to the same degree, we are probably justified for the time being in neglecting the effect of these factors. For experimental simplicity this assumption has been adhered to throughout this paper.

The hydrogen-ion concentration comparisons are made with juice extracted from the lower node. This node was chosen for two reasons: (a) it seemed the most likely part of the stem to show disease symptoms, (b) a very constant relation was found to exist between the hydrogen-ion concentration of the lower node and that of the roots. This is brought out by Table 3 and Fig. 2.

Figure 1.

Graph illustrating the influence of age on hydrogen-ion concentration.



Relation Between the Hydrogen-ion Concentration of the Stem and Lower Node

Table 3.

Date	Age	Root	Stem	Stage of Development
July 7	50	pH 5.418	pH 5.740	Vegetative
13	56	5.511	5.816	
Aug. 1	74	5.308	5.511	Milk
8	81	5.579	5.782	
Sept. 8	112	5.308	5.579	Dough
20	124	5.664	5.511	Ripe
26	130	5.664	5.562	Ripe

This table shows that until maturity was reached, the roots were consistently pH .2 to pH .3 more acid than the stems. After this stage the roots became slightly more alkaline than the stems. These results are striking-out of line with the laboratory findings in the first part of this article, which showed that the roots of the potted plants were more alkaline than the tops. The laboratory plants, however, were all seedlings not over twenty-eight days old and the data for field conditions were obtained on very much older plants, It is difficult to see why there should be such a marked difference in the two sets of results. For the present we may assume that the difference in soil conditions and growth phase are sufficiently great to account for such a change.

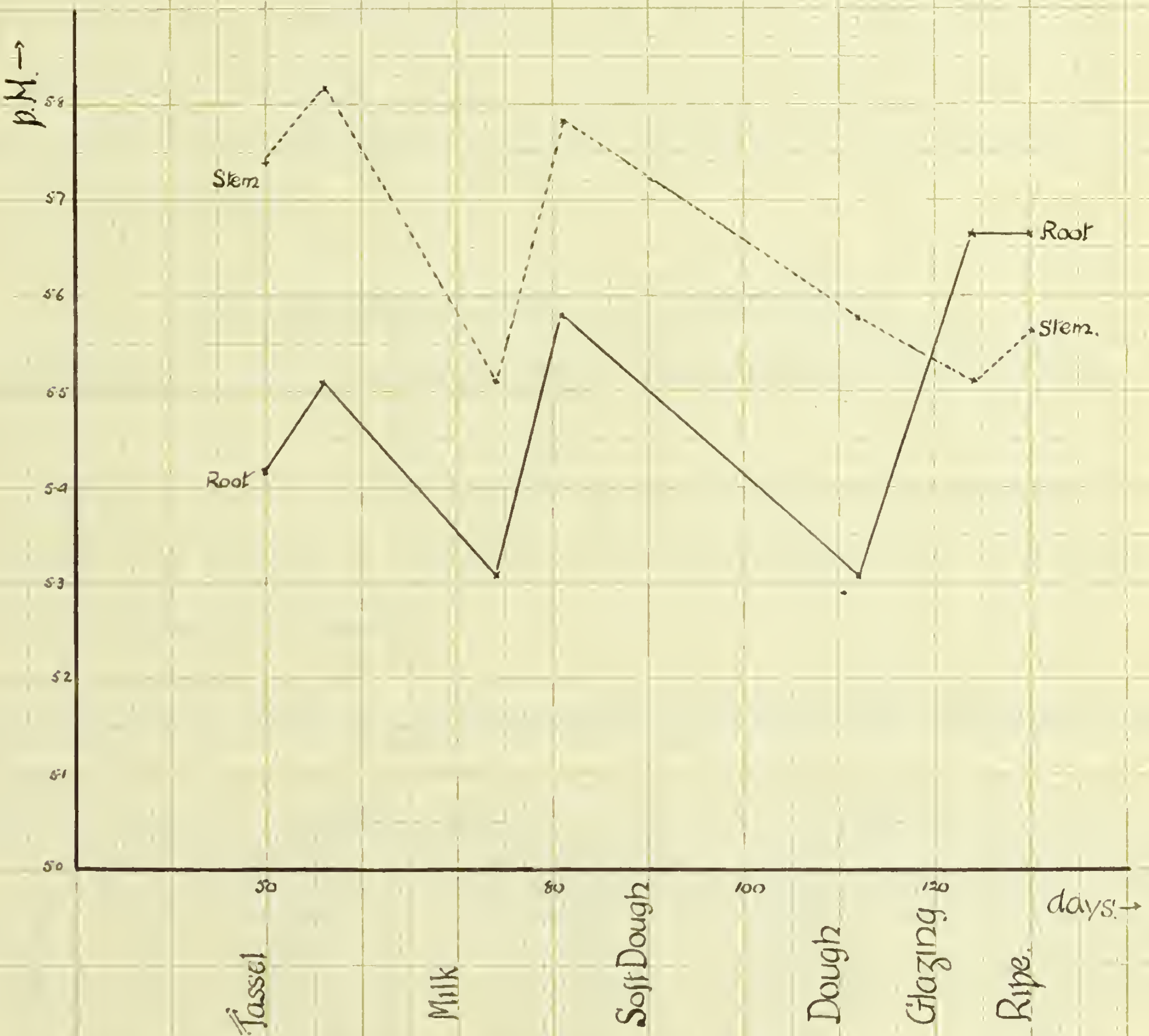
Comparison of the Hydrogen-ion Concentration of the Juice from the lower Node of Diseased and Disease free Corn

The data in Table 2 and Figure 1 can be used for the purpose of this comparison. These results were obtained from apparently sound plants grown on the unlimed soil.

A general study of this table seems to show no significant difference between the two strains. A difference can be brought out, however, if the dough stage is taken as the dividing line. Before this stage there seems to be no marked difference in the hydrogen-ion concentration. In two cases the

Figure 2.

Graph illustrating the variation in hydrogen-ion concentration between stem and root.



disease free corn shows the greater acidity and in three cases the reverse is true. After the dough stage is reached, however, the disease free corn consistently shows a greater hydrogen-ion concentration than the diseased. This confirms Hoffer's[11] work, but can be partly explained on the grounds that the diseased corn in this experiment tended to dry out more rapidly than the disease free. This drying out, probably due to a shortening of the life cycle of the diseased plants by the pathogenes, leads to a lowering of the hydrogen-ion concentration in the season.

The Influence of Liming on the Hydrogen-ion Concentration of the Juice from the Lower Nodes of Diseased and Disease Free Corn

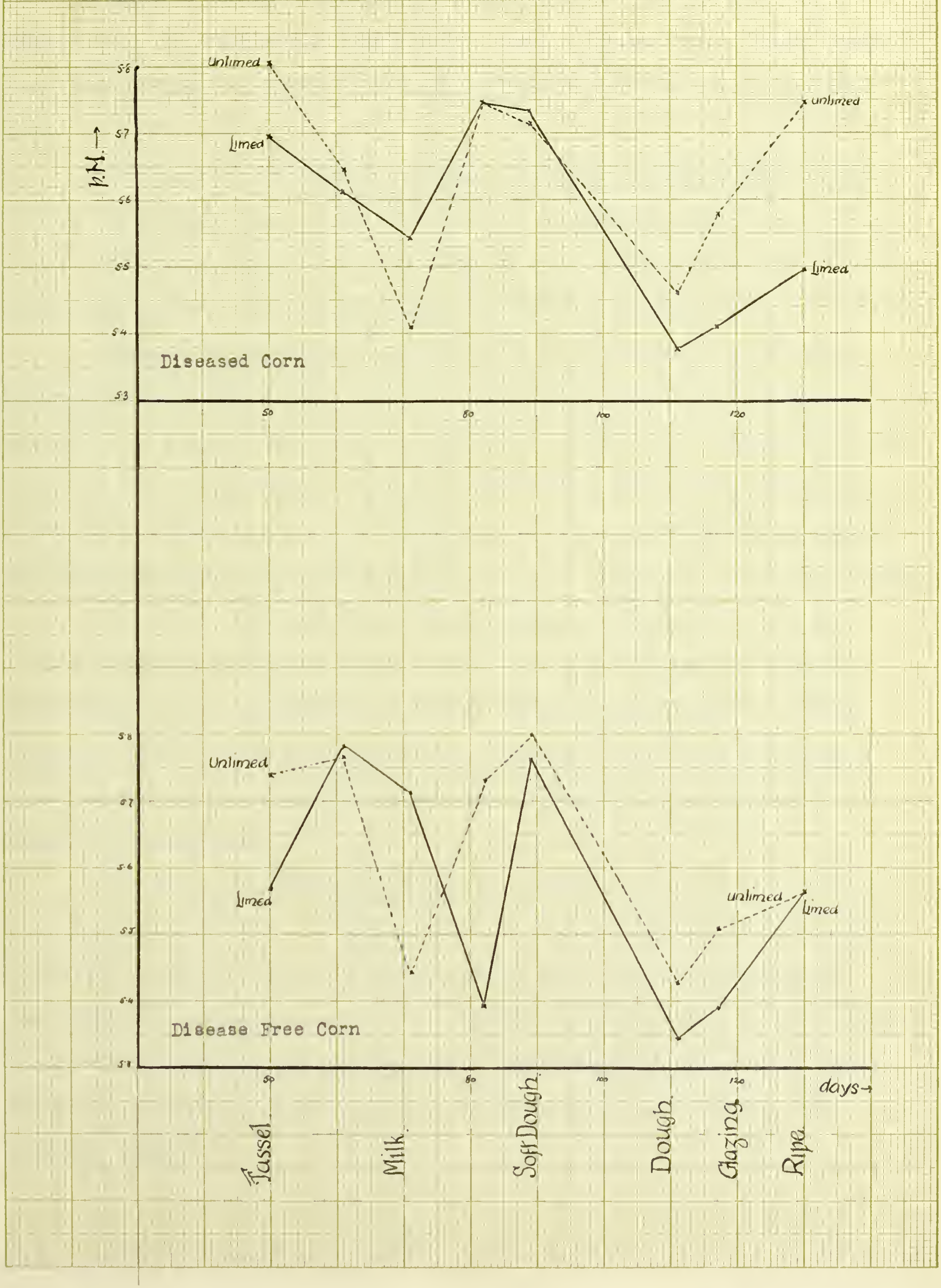
Plants for this test were pulled from the limed soil and compared with similar ones gathered at the same time from the unlimed soil. The results are given in Table 4 and Figure 3.

The Influence of Liming on the Hydrogen-ion Concentration of the Plant Juice

Table 4.

Date	Age	Disease Free		Diseased		
		Lime	No Lime	Lime	No Lime	Development
July 7	50	pH 5.567	pH 5.740	pH 5.692	pH 5.807	Veg.
18	61	5.782	5.765	5.613	5.647	Tassel
28	71	5.714	5.444	5.545	5.410	Milk
Aug. 9	82	5.393	5.731	5.748	5.748	
16	89	5.766	5.800	5.733	5.716	Soft dough
Sept. 7	111	5.342	5.427	5.375	5.461	dough
13	117	5.390	5.508	5.410	5.579	Glas-ing
26	130	5.562	5.562	5.493	5.748	Ripe

Graph illustrating the influence of liming on hydrogen-ion concentration.



There is too much variation in these figures to warrant any definite conclusions. The fact stands out, however, that by the end of the season liming seems to increase the acidity of the sap in both the diseased and disease free corn.

Instead of the lowering of acidity seen in the unlimed plants as they mature, the hydrogen-ion concentration seems to be maintained until later in the season. This is particularly true of diseased corn. This support, if it actually occurs, may partly explain the beneficial effect of liming under certain conditions.

Numerous pathogenes are very sensitive to pH changes in the nutrient material in which they occur. Therefore, by sustaining the hydrogen-ion concentration of the plant juice, liming may render the host less susceptible to the attack of root rot organisms. Whether it does this by actually increasing the hydrogen-ion concentration, or by increasing the vigor and therefore indirectly increasing the hydrogen-ion concentration, makes no difference to the final effect.

So far no marked differences in hydrogen-ion concentration have been brought out between the diseased and disease free corn. It was not, however, until September that any obviously diseased stalks were available for testing purposes. Only then was it possible to see if this difference in hydrogen-ion concentration was merely a natural phenomenon or whether it was the result of pathological conditions.

To investigate this point apparently disease free stalks were selected from the diseased rows on the unlimed soil and compared with stalks showing discoloration or decay in the lower nodes from the same rows. By longitudinal sectioning these diseased stalks were arbitrarily classified into groups consisting of slightly infected, discolored, badly infected and decayed stalks. These groups are illustrated by plates 6-10. Table 5 gives the pH values of the different groups.

The Influence of Disease on the Hydrogen-ion Concentration of the Plant Juice

Table 5.

Date	Age in Days	Apparently Disease Free	Slightly Infected	Discolored	Badly Infected	Decayed
Sept. 8	112	pH 5.579	5.782			7.033
14	118	5.253	5.337		7.624	
19	123	5.562		5.610		
20	124	5.596	5.816	6.103		
21	125	5.562		6.728 6.898		7.253
23	127	5.376	5.444		7.878	6.695
24	128	5.358			7.405	6.390
27	131		5.681		7.996 7.794 8.216	
28	132				6.948 8.047	7.472
Av		pH 5.470	5.612	6.335	7.738	6.968

Table 5 is open to several criticisms among which are: the arbitrary nature of the classification, the small number of readings recorded and the large amount of variation in these readings. To some extent this variation may be due to mistakes which could easily be made in classifying the stalks. It is clear, however, that there is a very decided lowering of hydrogen-ion concentration as the diseased condition develops, and a subsequent return to more or less neutrality soon after death.

Wagner , working along similar lines, reported the same premortal lowering of hydrogen-ion concentration in his diseased plants with what he called a "Post Mortalen Säuerung", or return of acidity, after death. The results described in Table 5 confirm his very well.

There is still the possibility that a change in hydrogen-ion concentration, similar to the one just described, may occur in normal stalks as they

mature and subsequently decay. Unfortunately the significance of the last set of results was not realized or the findings plotted, until it was too late to secure any more stalks. The pH values of the juice of two almost dead and three dead disease free stalks, which were apparently disease free, were secured, however, and they indicated that a decided decrease in acidity also occurs in disease free corn as it dries out. In fact Haas[7] describes a lowering of the hydrogen-ion concentration of the juice in the petals as a flower ripens, which is probably a similar phenomenon to the maturing of a corn plant.

This does not leave the matter altogether in doubt, as the change in hydrogen-ion concentration which occurs in diseased stalks shows itself before the stalks are mature. The diseased plants in Table 5 are not any more mature, when judged by external appearances, than the apparently disease free plants of the same table or the ripe diseased and disease free plants of Table 4.

From these results it seems evident that the disease brings about a decrease in the hydrogen-ion concentration of the plant juice. How it does this is not so clear. The decrease may be due to the direct activity of the pathogenes, or to a premature maturity brought about by their activities. In either case the effect is the same - the hydrogen-ion concentration of the juice is lowered before the plant is ready to mature in the normal fashion.

SUMMARY

These preliminary investigations cover only one season and the amount of data accumulated is small. Under the conditions described, however, and as far as the experiments have gone, the following conclusions can be drawn:

(1) Under "normal conditions" environmental factors such as temperature, moisture and light, do not necessarily produce any marked effect on the hydrogen-ion concentration of the plant juice.

(2) There is a progressive change in the hydrogen-ion concentration of the juice as the corn plant develops. The acidity is low to begin with, reaches a maximum about the milk or dough stage, and subsequently declines as the plant matures.

(3) Liming apparently does not effect the hydrogen-ion concentration of the juice until the plant has reached the dough stage.

(4) Disease lowers the hydrogen-ion concentration of the plant juice.

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NOTE

Anton Eric Romyn was born at Pretoria, South Africa, July 20, 1894. He received his high school training in South Africa, graduating in 1910. His undergraduate work was taken partly at the South African College and partly at the University of Toronto, from which he obtained the B.S.A. degree in 1916. He entered the University of Illinois in 1919, receiving a M.S. in Animal Husbandry in 1920. While at the University of Illinois he was for some time on the faculty as an Assistant in Animal Husbandry.

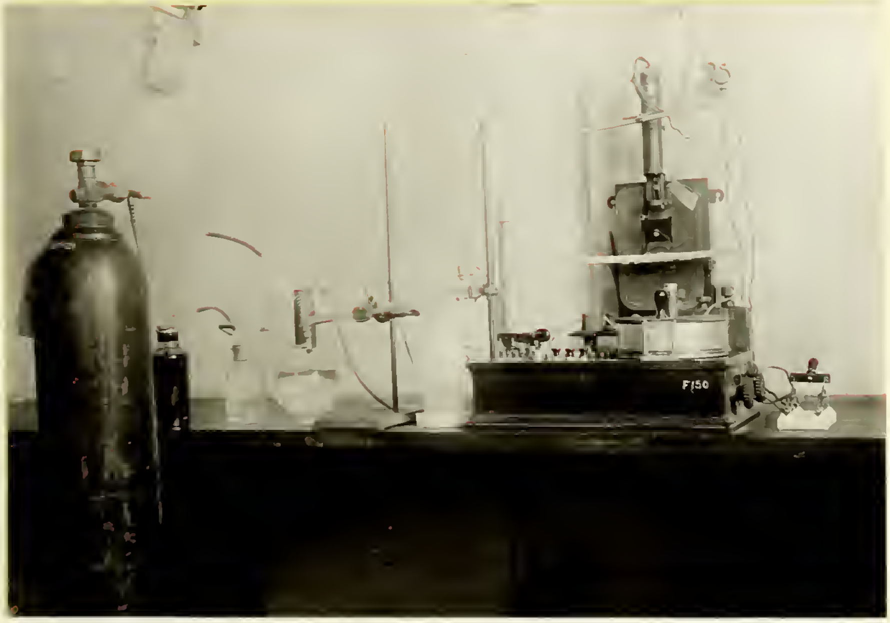

Plate 1 Hydrogen-ion Apparatus

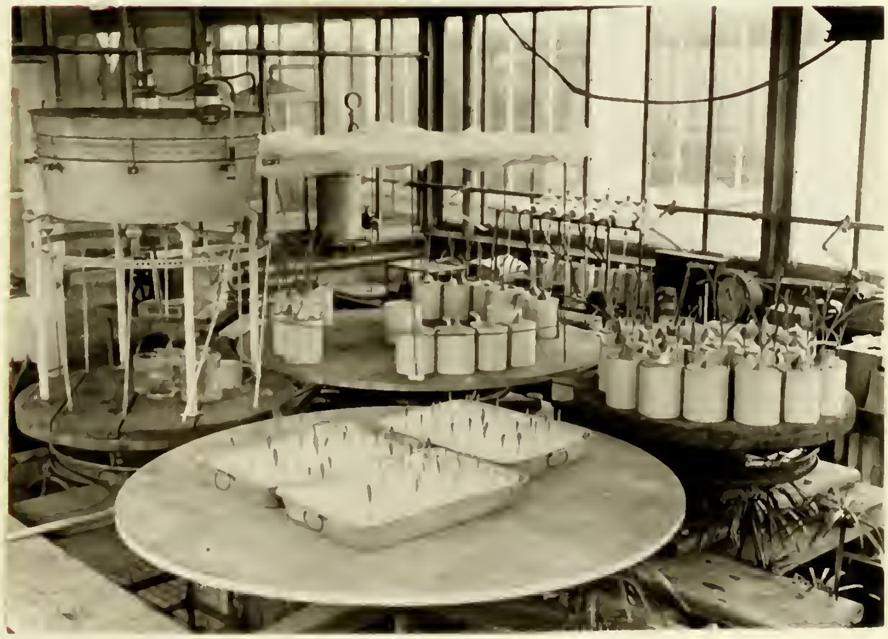

Plate 2 Revolving Table and Pots

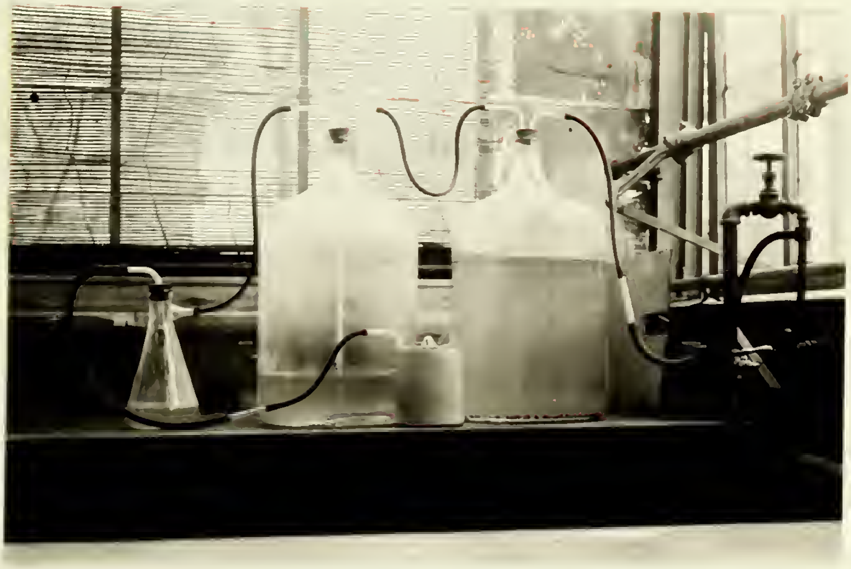

Plate 3 Aeration Apparatus

The large bottles are graduated so that a known quantity of air can be drawn through the small pot.

Influence of Aeration

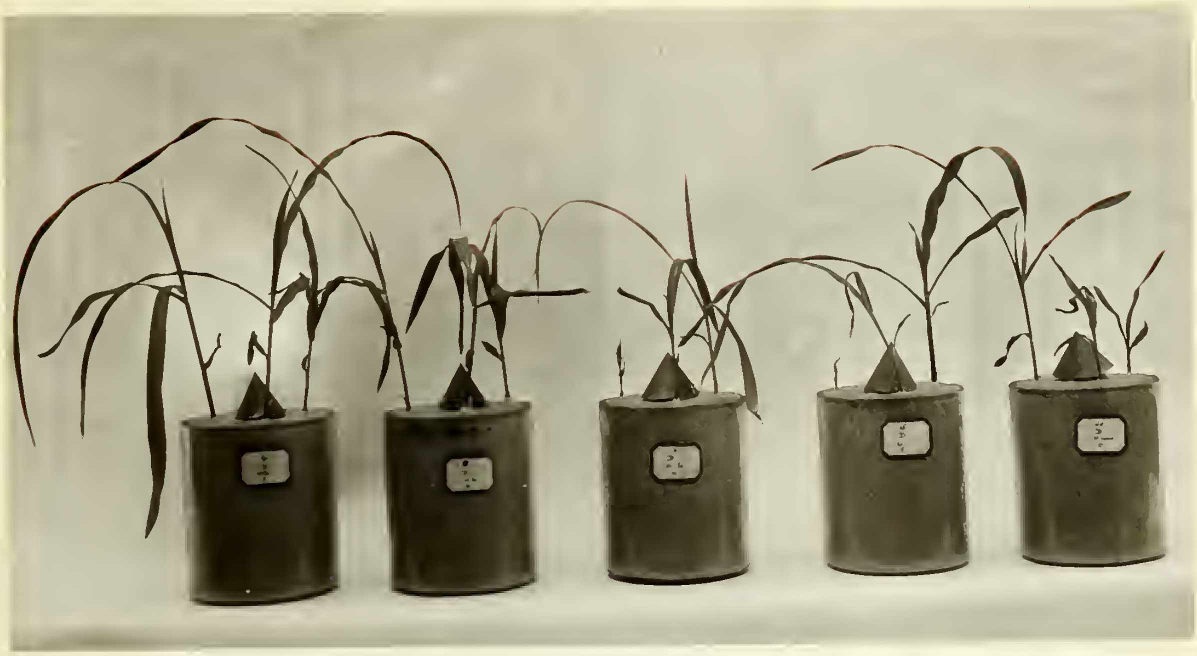

Plate 4 "Diseased" Pots

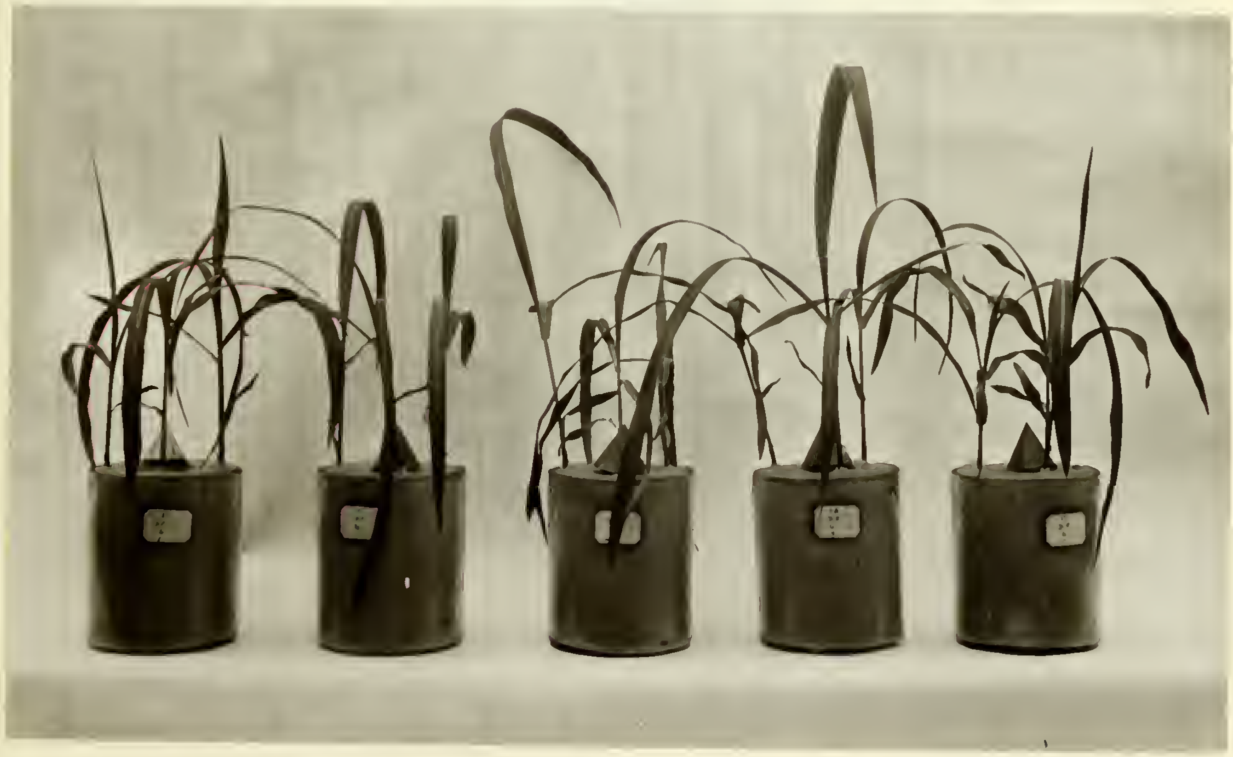

Plate 5 "Disease Free" Pots

Numbering from the left, the pots in each set were aerated every one, two, four, eight days, and not at all.

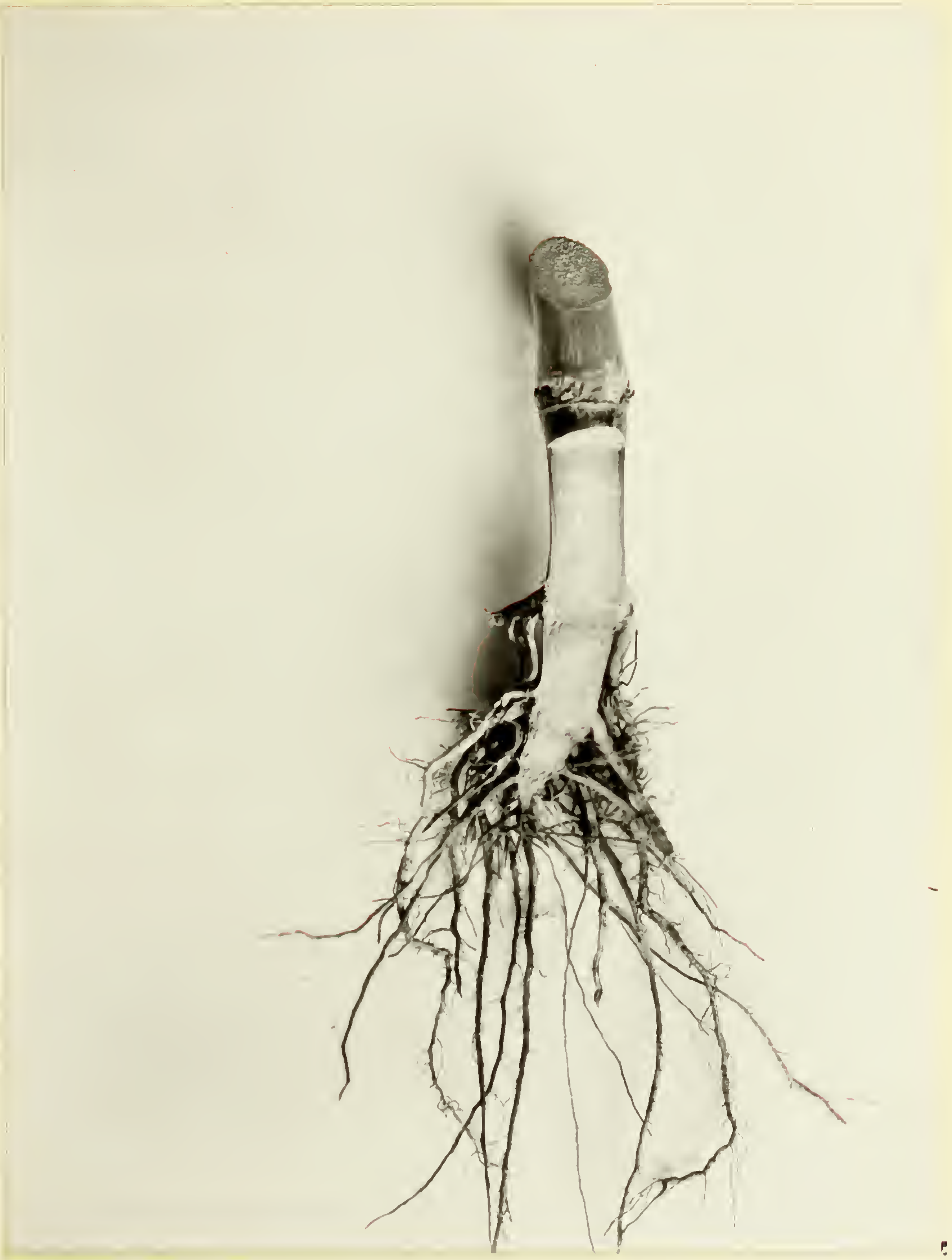

Plate 6 "Diseased" Stalk, apparently Disease Free pH 5.470

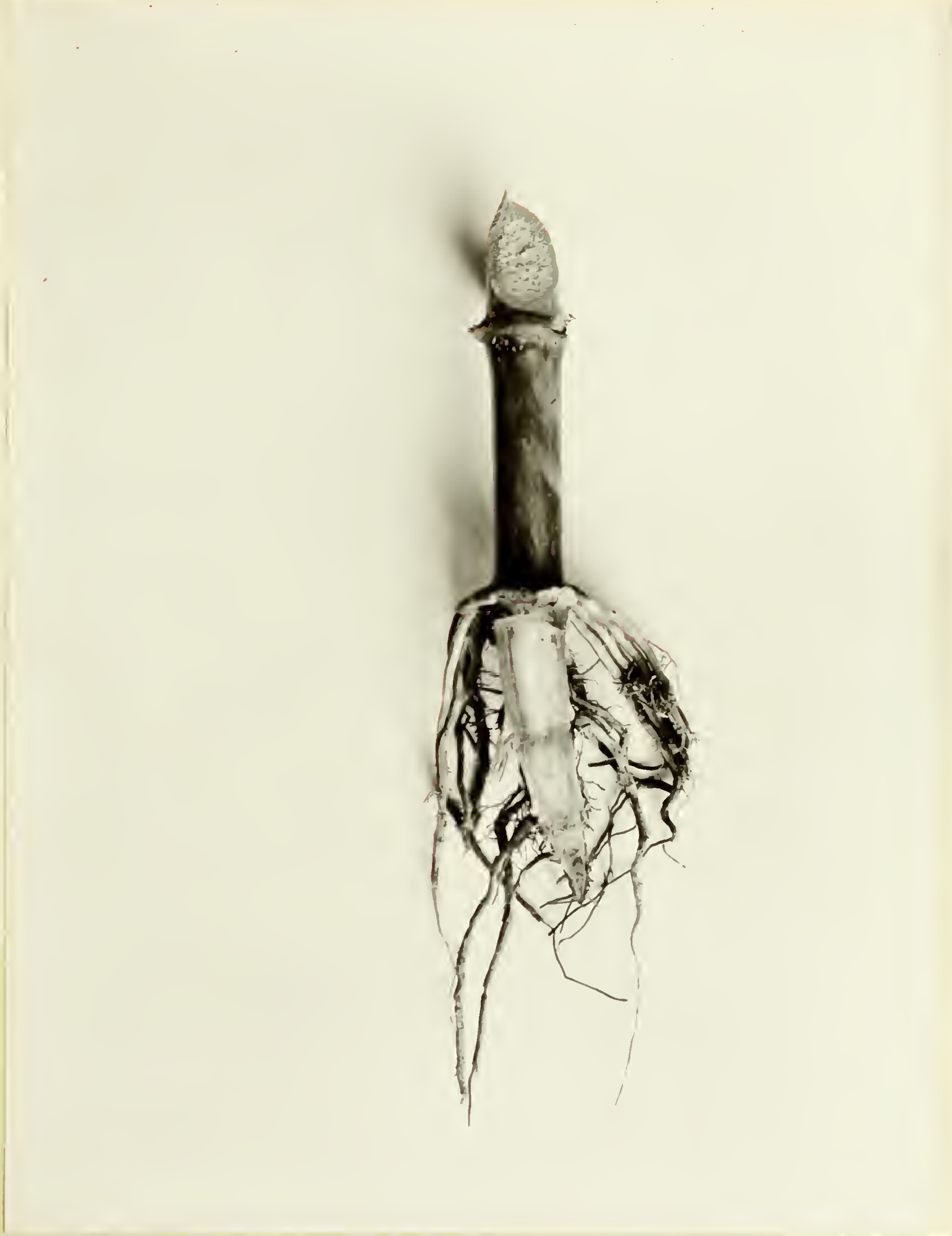

Plate 7 "Diseased" stalk, slightly infected pH 5.612

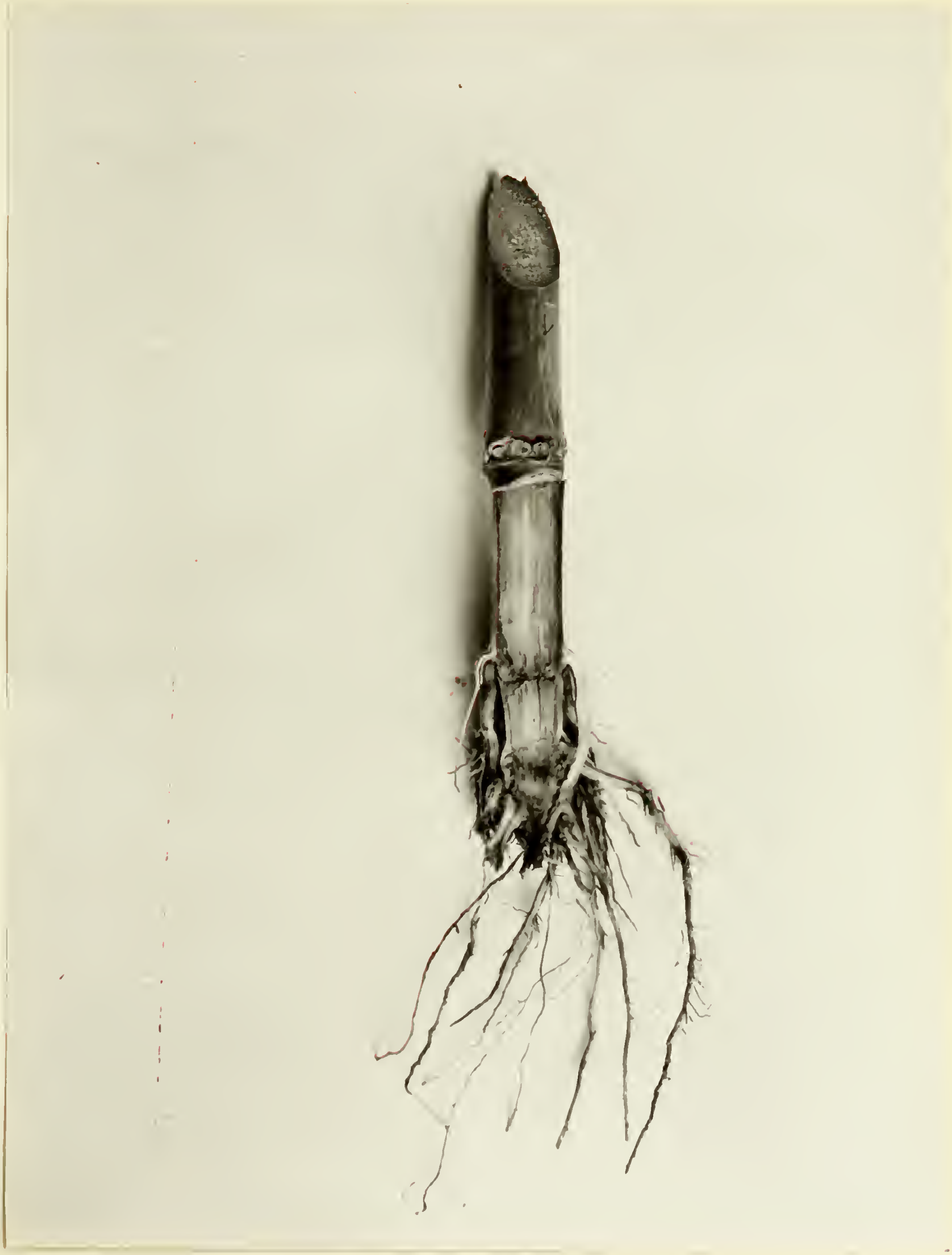

Plate 8 "Diseased" Stalk, discolored pH 6.335

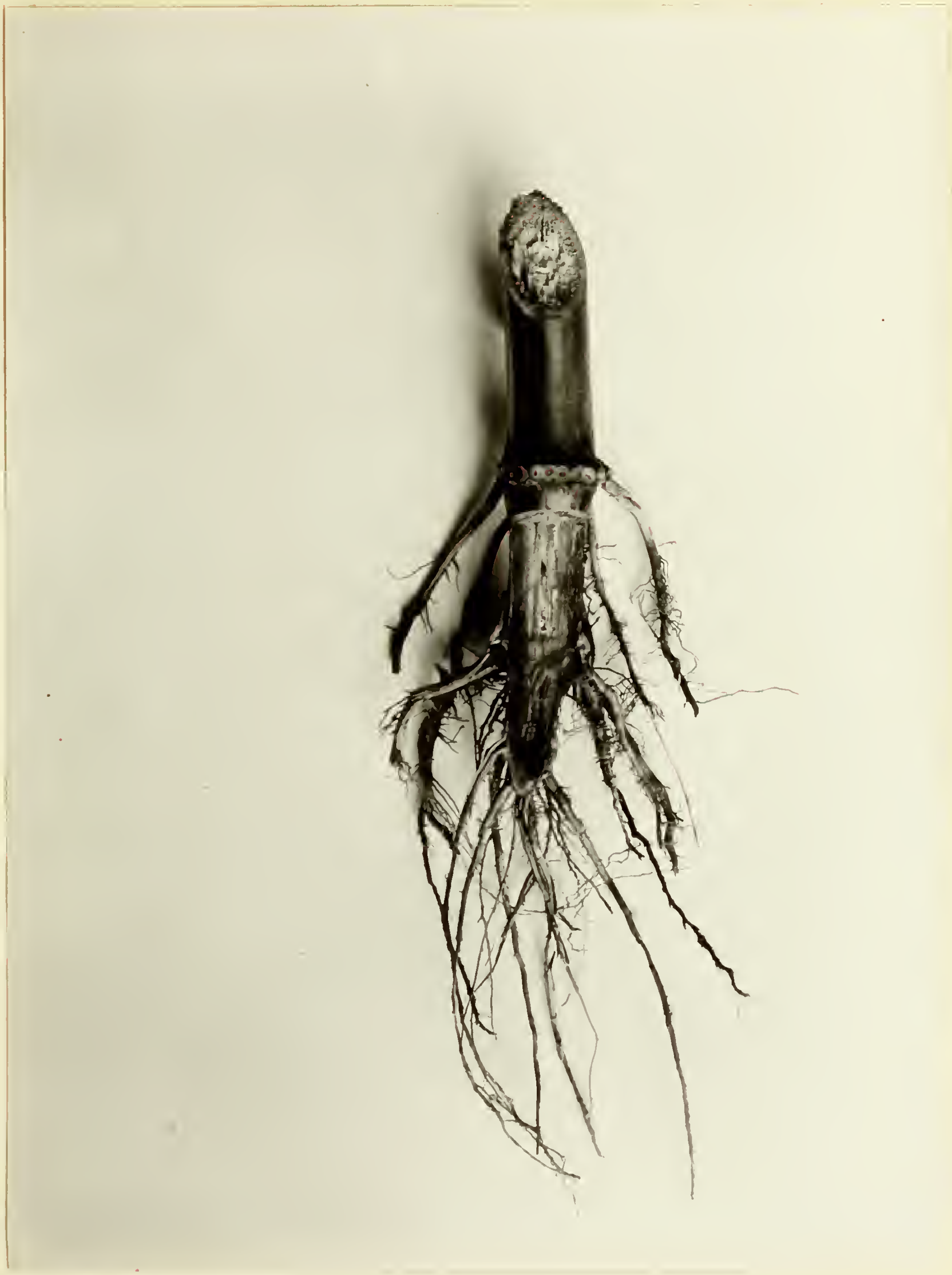

Plate 9 "Diseased" Stalk, badly infected pH 7.738

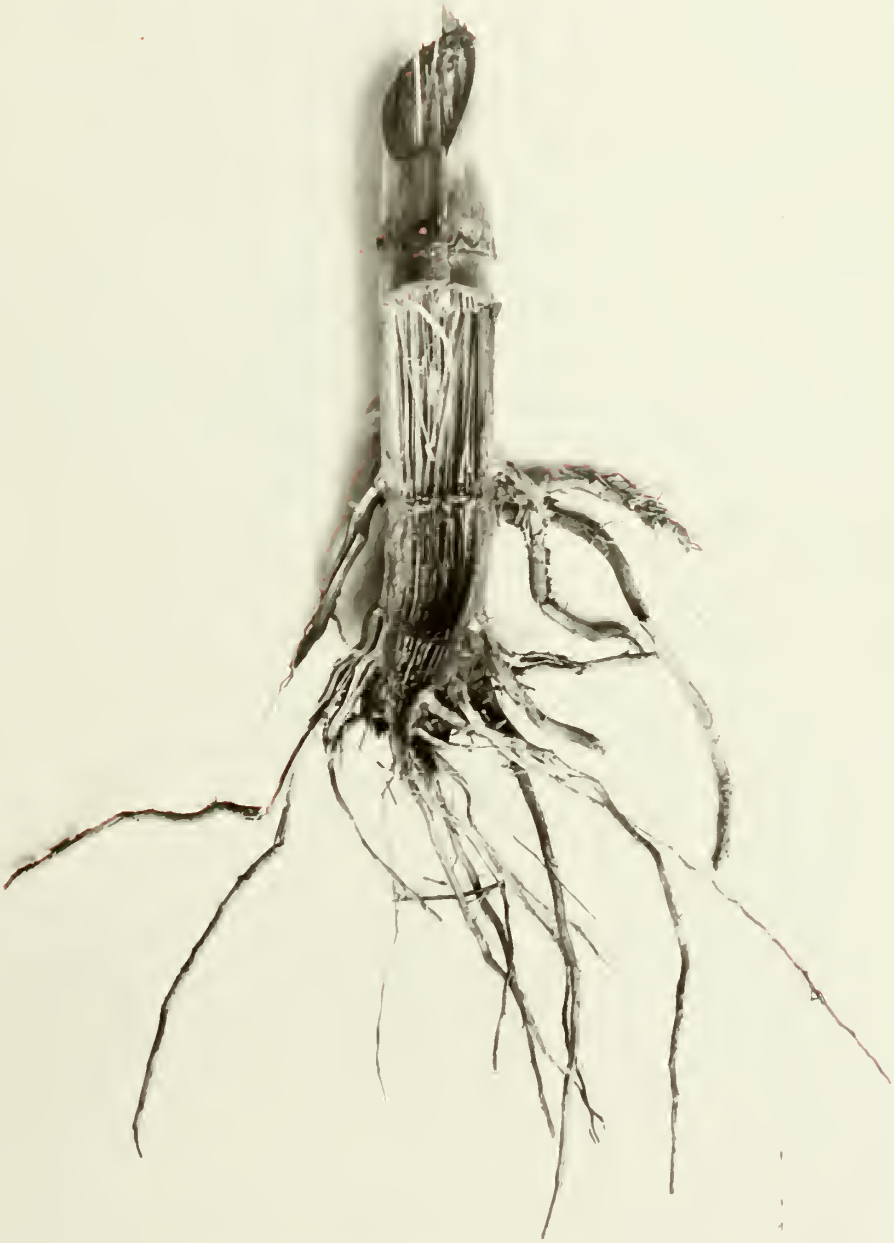

Plate 10 "Diseased Stalk", decayed pH 6.968

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